RP 821 Wind Turbine Blade Condition Monitoring

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chairs:
Bruce Hamilton, Navigant Consulting
Jim Turnbull, SKF
Primary Author: David Clark, Bachmann

Purpose and Scope

Blade condition monitoring systems may be capable of detecting and predicting failures and conditions that would otherwise be difficult or un-detectable in megawatt class wind turbines (this is not accurate, almost all are detectable with visual inspection). Several technologies have been tried or adapted from other markets with varying ability to detect emerging failure modes. While a mature system is currently not yet commercially available, the scope of “Wind Turbine Blade Condition Monitoring” provides insight into these technologies and discusses common failure modes of wind turbine blades.

Condition monitoring of blades may be required in the future as wind turbines and blades increase in size or complexity, new insurance or lender requirements emphasize predictable reliability, and offshore wind turbines increase in number.

Introduction

There are six major failure modes that can be monitored by a blade condition monitoring system. To date, no commercially available system available is capable of detecting all major failure modes, although several approaches have been tested in the recent decade.

Historically, there have been many attempts at adapting technologies from other industries to this application with limited operational or commercial success. In order to gain market acceptance, any blade condition monitoring system must be able to detect (unknown failures, trend damage progression, and confirm) known failure modes, be easily installed in existing towers, be sufficiently robust to withstand operational and environmental conditions, and provide reliable, cost-effective data on blade condition.

Wind Turbine Blade Condition Monitoring

1. Issues

There are three major concerns that must be addressed by a potential blade monitoring system:

- The technology or product must detect the likely encountered failure modes.
- The system must be capable or retrofitting existing towers.
- The system must be cost effective.

There is a new patent which does show promise in addressing all three of these issues.

2. Failure Modes

Figure 2. A typical blade plan and region classification.

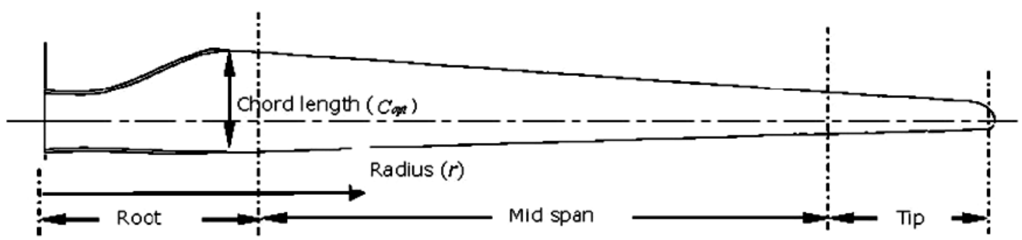

Figure A: A Typical Blade Plan and Region Classification.

2.1. Cracks

The ability to detect and provide early warning of cracks that typically occur at four common locations is a critical feature of blade condition monitoring. These crack locations include the root, leading edge, trailing edge, and tip, as shown in Figure A. While there is some uncertainty as to where a crack might occur in these locations due to variables from one blade manufacturer to the next, these four locations are generally consistent.

2.2. Delamination

Delamination predominately occurs at the trailing edge location and is caused by separation of the layers of composites and laminations. Separation may be caused by poor structural design, resin-rich areas with inadequate reinforcing matrix, poor quality control in manufacturing, accumulated stress-fatigue damage, and other factors.

2.3. Icing

An accumulation of ice on the blade surface is not conducive to safe or reliable wind turbine operation. Performance is degraded and the extra loading of ice on blades creates measurably uneven stresses. A blade monitoring system should be able to measure this accumulation of ice on the blades and provide the operator with a warning if loads exceed an established action threshold under operating conditions.

2.4. Imbalance (Either Aerodynamic or Static)

While blades are balanced from the factory within a tight tolerance, the operating environment and in-service wear or damage, e.g. leading edge erosion, may contribute to static imbalance in the field. In addition, aerodynamic imbalance may be result from variations in pitch index or sweep, improper placement of vortex generators or other aerodynamic aids, and variations in a blade's aeroelastic behavior.

There may also be uneven loading issues caused by wind shear, pitch deviation, tip in/out, and yaw deviation. All of these conditions can be monitored and will return improved performance, reliability, and production. If not monitored correctly, these operational conditions may appear as imbalance, but a best practices blade condition monitor and a trained analyst should be able to discern between these differences. In fact, this is an important function of a legitimate analyst.

2.5. Lightning Strikes

A blade condition monitoring system should be able to detect lightning strikes which contribute to one of the acknowledged failure modes. Like icing, lightning is very common in certain geographical locations. Therefore, best monitoring practices would dictate a system capable of detecting the occurrence of lightning strikes.

3. Technology Approaches

While no single product or technology today can measure or detect all of the possible failure modes common in a wind turbine blade, there are many current efforts that show promise for future applications. Below are the different technologies that may be applied:

3.1. Fiber Optic

Fiber optic sensors provide fast, high-resolution strain data from structures. They are light weight and would not affect performance. However, they are also difficult to install outside of initial blade manufacture, expensive, and do not detect all failure modes. This is likely why fiber optic technology has had limited success and adoption in the wind industry, although it is quite common in the aerospace industry. Installation usually involves cutting a shallow slot into the perimeter of the blade where the fiber optic strand is then laid and epoxied in place.

3.2. Strain Gauges

Strain gauges are inexpensive and easy to install/retrofit to existing turbines, but have proven to be troublesome in the field, having a lifetime as short as 6-9 months. Like fiber optic sensors, strain gages do not detect all blade failure modes, and their deployment has had limited success.

3.3. Acoustic

One wind turbine manufacturer has experimented with acoustic monitoring technology to detect blade cracks on a small number of towers. A focused microphone was placed on the top of the nacelle pointing forward towards the hub in an attempt to detect high-frequency acoustic signatures emitted by surface blade cracks. The detection capability of acoustic technology is limited to surface cracks and will not necessarily identify sub-surface delamination or uneven stress loading. While easy to install/retrofit, and relatively cost effective, acoustic technology has not been successful in the wind industry for the same reasons as fiber optic technology.

3.4. Vibration Sensors

This approach has been used with the sensors mounted near the hub, not on the blades. There is good measurement ability in some failure modes such as icing, imbalance, and less than optimal operational conditions. Again, there is limited detection capability for all common failure modes, but ease of installation or retrofit and cost-effectiveness are good. As a secondary benefit, vibration sensors for blade monitoring are usually applied at the main shaft bearing, which is also monitored. While main bearings are the least frequent failure in most drive trains, they are expensive to repair. Main bearing monitoring is an added benefit of this technology.

3.5. Laser Reference

This method utilizes a laser and prism system to compare the spatial differences and changes between known reference points within a wind turbine blade. This is done by aiming the laser at the prism and then re-directing the laser to internal locations. This technology would provide an excellent system for quality control of blades to measure manufacturing deviations in substrates and composites. Once again, the inability to detect all common failure modes, complexity of retrofit, and system cost all contribute to a lack of widespread acceptance.

4. A Perfect System Summary

As a note to system designers and integrators, the perfect wind turbine blade condition monitoring system would have the following features:

- The ability to detect all 6 common failure modes
- Robust sensors
- The ability to provide blade and blade position identification
- The ability to provide sensor identification
- A cost-effective method for either retrofit to existing turbines or installation at original manufacture
- Wireless and self-powered sensors to facilitate installation and data collection

5. Analysis and Software

Any good condition monitoring system is only as effective as the analyst who configures the alarms, monitors the data, and performs the analysis. So even with perfect blade CMS hardware, there is still a need for a certified and experienced vibration analyst with familiarity in wind turbine blade defect analysis to set-up and monitor the CMS for results.

Software should be able to configure appropriate measurements, alarming and displaying blade data in a familiar condition monitoring format consistent with industry standard vibration analysis practices and norms. This means industry standard measurements, units of measurements, labeling, measurement set-ups, alarming, charting and reporting.

With the blade CBM data streaming (off of the blades, tower, farm, and fleet), special considerations need to be made for appropriate data transportation, data storage, and resulting data analysis with the aforementioned software and appropriate analysist.

Reference

[1] P. J. Schubel and R. J. Crossley, “Wind Turbine Blade Design,” *Energies*, vol. 5, no. 9, pp. 3425-3449, Sept. 2012.